Using the EN584-1 film characterization in radiographic modelling

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Abstract
One of the problems in modelling radiographic inspections concerns the film characteristics as the last step in the radiographic modelling chain, throughout which the energy deposited by the incoming radiation is to be converted to a grey value. This conversion depends not only on the total dose absorbed by the film, but also on the radiation's spectrum and to a lesser extent also on the incidence angle of the incoming radiation. Models trying to take all or most of these influential parameters into account inevitably lead to complex and proprietary film characterizations, and in particular require information generally not available in the film data sheets provided by the manufacturers.
The recent EN584 standard for the classification of film systems for industrial radiography proposes a pragmatic and in many cases sufficient classification in terms of the dose required to obtain optical density 2, and the gradient of an optical density vs. required dose at optical densities 2 and 4. In this paper, we discuss different ways to implement an EN584-compliant film model.

Keywords: Radiography, Simulation, Film

1. Introduction

Radiographic modelling ultimately requires converting the incoming radiation, attenuated and scattered by the inspection part, into an optical density according to the film's characteristic response curve.

If this conversion is done on a photon level, as is possible with Monte-Carlo methods, it is possible to take into account the energy and incidence angle of each photon arriving at the film, albeit at a considerable computation cost. An alternative approach consists in reasoning in terms of an incoming spectrum, neglecting photon incidence, or simpler yet, an incoming radiation dose.

With increasing complexity of the film model, more information about the film is required: The Monte-Carlo film model in Moderato [1] is able to model the influence of the detector composition, but requires information such as the number of silver bromide grains per volume unit of the film, and their average diameter. This information is rarely made available by film manufacturers.

The EN584 standard proposes a pragmatic and well defined classification of industrial radiography films, and lends itself to a surprisingly simple and useful simulation model.

2. The EN584 film model

2.1 Scope

The EN584 film standard [2] was not written with computer modelling in mind, but in order to provide a reliable means to classify film systems used in industrial radiography.

A film is described in terms of the dose required to obtain optical density 2, and the gradient of an optical density vs. required dose at optical densities 2 and 4. Furthermore, classification according to EN584 requires the measured granularity and the gradient to granularity ratio, both at optical density 2. The standard describes in detail the conditions under which film samples must be exposed, developed and evaluated to obtain its EN584-compliant characterization.

During film characterization, a density versus dose (D vs k)-curve is obtained for the entire range of optical densities between 1 and 4.5, for which the norm stipulates at least 12 discrete sampled values. The three characteristic values k_s (dose required to obtain optical density 2), G2 (gradient at optical density 2) and G4 (gradient at optical density 4) are extracted from these measurements, and only these three values are published in the certificate, together with the measured granularity at D=2 and the calculated value of the gradient to noise-ration G/σ_D.

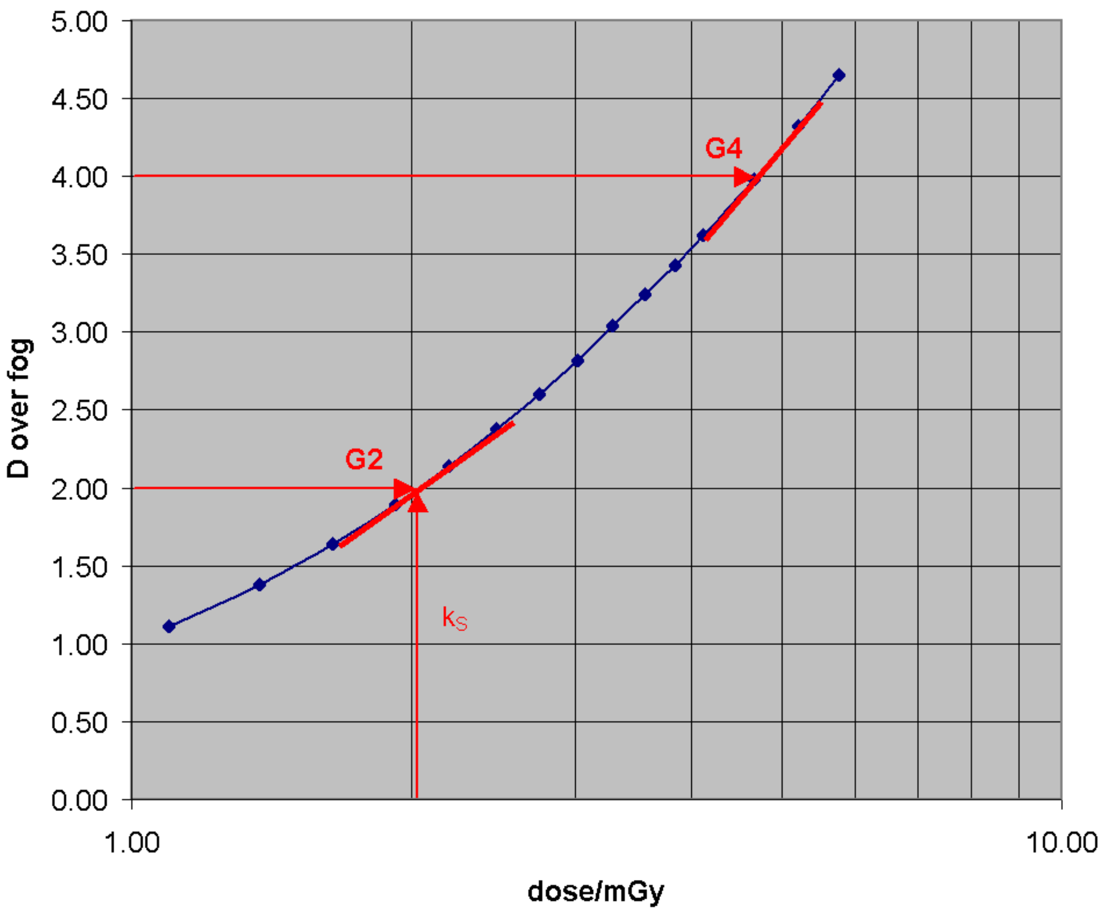

figure 1: incoming dose vs. optical density curve, with characteristic values k2, G2 and G4

2.2 CEN-speed: A linear model

The most straightforward implementation of the EN584 standard treats the film as linear, and relies only on the CEN speed value S, defined in terms of the reciprocal of the dose k_2 required to obtain optical density 2 (referred to as k_s in the standard), rounded to the closest of 25 tabulated values. D_0 denotes the measured optical density of an unexposed film and includes fog and base density.

$$D(k) = D_0 + 2Sk \qquad \text{with } S = \frac{1}{k_s}$$

Since EN584 associates a range of k_s values to each of the 25 tabulated CEN speed values (e.g. values of $1/k_s$ between 91 and 112 are attributed to CEN speed 100), a linear model seems quite appropriate, if no further information about the film is given.

2.3 A second order model

A second order approximation can easily be derived if the gradient G_2 at optical density 2 is also taken into account. The gradient values G_2 and G_4 relate to a D versus $\log_{10}k$ curve

$$G = \frac{dD}{d\log_{10} k} = \frac{K}{\log_{10} e}\frac{dD}{dk}$$

The second order approximation for D(k) then becomes

$$D(k) = D_0 + 2Sk + ck^2 \qquad \frac{dD}{dk} = \frac{2}{k_s} + 2ck$$

$$= D_0 + \frac{2}{k_s}k + ck^2$$

with

$$c = \frac{G_2 \log e - 2}{2k_s^2}$$

This model is available in Moderato 3.0, together with the linear ISO speed model and a tabulated conversion.

2.4 Validation

This simple quadratic model deliberately ignores the G_4 gradient. To verify whether the second order approximation is acceptable or not, D(k) curves calculated using this model were compared to experimental values obtained at BAM for a number of major NDT films.

For the most non-linear film compared, the difference observed at optical density 4 was less than 5%, which is excellent agreement considering that the EN584 standard accepts

an uncertainty of ±5% for the G_2 gradient, and even ±7% for G_4. This result suggests that a refined third order model which would take G_4 into account would provide little benefit.
Figure 2 confronts the linear and second order model to actual measurements for the most non-linear film found (a C6 class film).

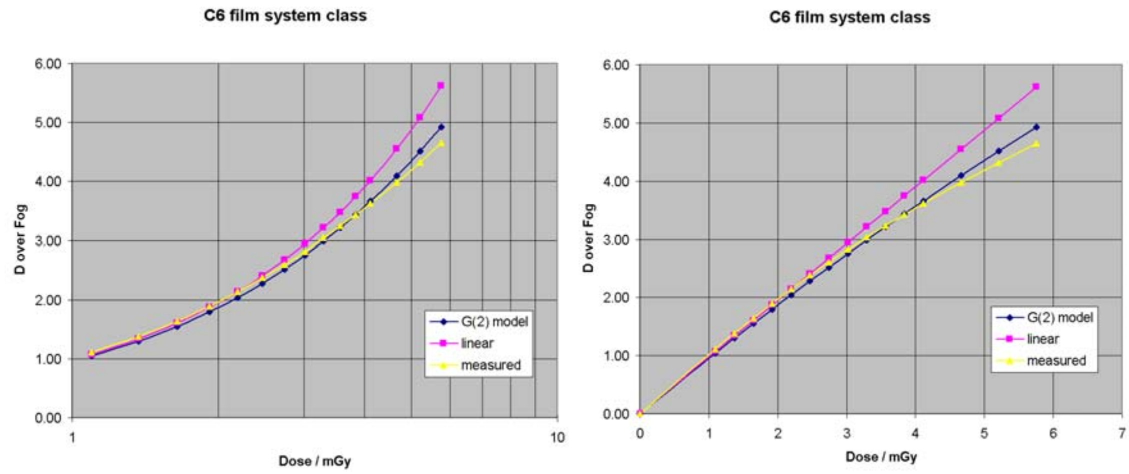

Figure 2: Comparison of linear and second order model with measured dose vs. optical density curve (C6 film system class)

3. Conclusions

The EN584 standard lends itself to a pragmatic film model for computer models. In this article we described a second order model, which proves to represent well the dose to optical density conversion curves obtained during characterization. The comparison suggests that a 3rd order model promises little additional precision.

The EN584 characterization neglects the photons quantum energy, and is therefore strictly valid only for the complete film system. The transfer to other radiation spectra or films using different screens therefore requires further considerations, which are the subject of current work, as is the integration of granularity into our model.

References

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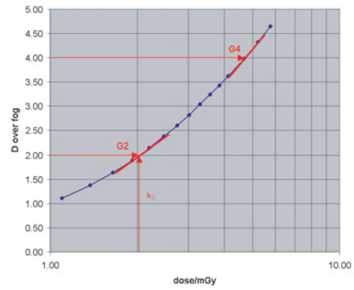
EN584 and the radiographic modeling chain

One of the problems in modeling radiographic inspections concerns the film characteristics as the last step in the radiographic modeling chain, throughout which the energy deposited by the incoming radiation is to be converted to a gray value. Models trying to take all or most of these influential parameters into account inevitably lead to complex and proprietary film characterizations, and in particular require information generally not provided by the film manufacturers.
The EN584-1 standard for the classification of film systems for industrial radiography (recent revision in 2006) proposes a pragmatic and in many cases sufficient classification in terms of the dose required to obtain optical density 2, and the gradient of an optical density vs. required dose at optical densities 2 and 4. During film characterization, a density versus dose (D vs k)-curve is obtained for the entire range of optical densities between 1 and 4.5, for which the standard stipulates at least 12 discrete sampled values (example for C6 film shown). The three characteristic values k_S, G_2 and G_4 are extracted from these measurements, and only these three values are published in manufacturer certificates.



Implementation

The most straightforward implementation of the EN584 standard treats the film as linear, and relies only on the CEN speed value S, defined in terms of the inverse of the dose k_2 required to obtain optical density 2 (referred to as k_S in the standard). D_0 denotes the measured optical density of an unexposed film and includes fog and base density.

$$D(k) = D_0 + Sk \qquad \text{with} \quad S = \frac{1}{k_s}$$

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$$= D_0 + \frac{2}{k_s}k + ck^2$$

with $$c = \frac{G_2 \log e - 2}{2k_s^2}$$

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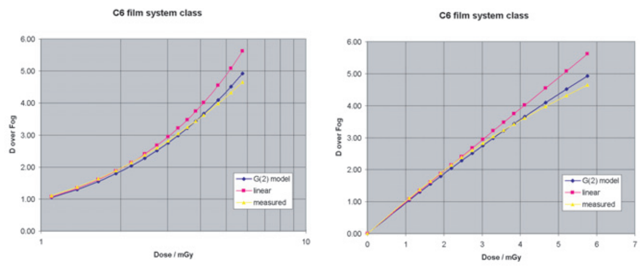
Validation

This simple quadratic model deliberately ignores the G_4 gradient.
To verify whether the second order approximation is acceptable or not, D(k) curves calculated using this model were compared to experimental values obtained at BAM for a number of major NDT films (example for C6 film shown in linear and logarithmic scale).

For the most non-linear film compared, the difference observed at optical density 4 is less than 5%, which is excellent agreement considering that the EN584 standard accepts an uncertainty of ±5% for the G_2 gradient at even ±7% for G_4. This result suggests that a refined third order model which would take G_4 into account would provide little benefit.



Perspective

The EN584 characterization neglects the photons quantum energy, and is therefore strictly valid only for the complete film system. The transfer to other radiation spectra or films using different screens therefore requires further considerations. Film manufacturers data sheets suggest to take different radiation spectra into account by a simple weighting factor, and provide these for 100keV, Ir192 and Co60 exposures.

Another aspect of the EN584 model has not yet been integrated into our model: The standard also defines a granularity measurement procedure, and stipulates that granularity at optical density 2 σ_D and the calculated gradient/noise ratio G/σ_D be provided.

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